4.0 SAFETY ASSESSMENT

4.1 METHODOLOGY

This safety assessment is designed to determine the net safety benefit associated with inerting. Section 4.2 provides an overview of the flammability exposure analysis tool that was used to determine the effectiveness of inerting systems. Sections 4.3 and 4.4 discuss potential new hazards that must be addressed with the implementation of any inerting system design. Section 4.5 describes the approach for calculating safety benefits from inerting. Sections 5.0 through 9.0 discuss the safety benefits for each design concept.

4.2 FLAMMABILITY

Understanding flammability relies on the science of quantifying when a fuel vapor/air mixture will burn upon introduction of an ignition source.

Jet fuel is a blend of more than 300 different hydrocarbons. When fuel is added to a tank, a certain percentage of the fuel vaporizes, with more of the light hydrocarbons evaporating than the heavy ones. The resulting vapor displaces some of the air in the tank and mixes with the air to create a fuel-to-air mixture in the ullage (i.e., portion of the tank volume not occupied by fuel).

The amount of fuel vapor present in the fuel tank ullage is driven by the vapor pressure of the fuel, which is strongly affected by the fuel temperature. Therefore, the flammability of ullage depends on the fuel temperature while the airplane is on the ground, and on how it cools during the climb and cruise.

This fuel vapor/air mixture can be ignited when the ratio of fuel to air is within a certain range between the lean and rich limits. For jet fuels, this combustible fuel-to-air ratio ranges from a lean limit of around 0.03 (1 lb of fuel vapor to 33.3 lb of air) to a rich limit of around 0.24 (1 lb of fuel vapor to 4.2 lb of air). Within this fuel-to-air ratio range, a spark, arc, hot surface, or other ignition source can ignite the fuel vapor/air mixture. Outside these limits, the fuel is either too lean or too rich to burn.

The energy needed to ignite fuel vapors varies as a function of the fuel-to-air ratio. The lean and rich ends of this ratio require higher spark energy—more than 1,000 mJ. In the middle of the flammable fuel-to-air ratio range, at around 0.08 (1 lb of fuel vapor to 12.5 lb of air), the ignition energy needed drops to 0.25 mJ, or 5,000 times less than is needed at the lean and rich limits. For reference, a jet engine igniter plug has a single-spark discharge of around 5,000 mJ, and a person walking across a carpet in dry weather can create a spark of around 10 mJ. An increase in altitude increases the energy required to ignite the mixture.

Fuel tanks become more flammable as the airplane climbs, as a result of pressure decrease. While the amount of fuel vapor doesn’t change, pressure influences the fuel-to-air ratio because the amount of air in the tank lessens with altitude. At constant temperature, this causes the fuel-to-air ratio to increase. Modeling assumes a lean flammability limit temperature reduction of 1°F for each 808 ft of altitude gained.

The amount of fuel in the tank has an effect on the fuel-to-air ratio because the mixture of different hydrocarbons in fuel evaporates to reach equilibrium. If there is only a small amount of fuel in the tank, the fuel may run out of light hydrocarbon components and a lower fuel-to-air ratio results. This effect exists at low fuel quantities, generally near the unusable quantity of the tank.

A flash point test is a simple test run at sea level to find the temperature at which a small flame will ignite a fuel vapor/air mixture in a small chamber. The flash point is useful for comparing one fuel to another and is about 10˚F above the lean flammability limit for jet fuels. Testing by the University of Nevada at Reno for the FAA has established that the flash point temperature, determined by the American Society for Testing and Materials (ASTM) Standard D 56, gives a fuel-to-air ratio of 0.044 for most Jet A type fuels.

The FAA has developed a computer program to compute the fuel-to-air ratio for a wide range of temperatures, altitudes, and fuel loads for jet fuels. It uses the ASTM D2887 distillation curve to define the fuel in question. This program was made available to and modified by the FTIHWG. The following paragraphs describe the customization of this model for ARAC analysis.

4.2.1 Inerting

Inerting is the process of reducing the amount of oxygen in the tank ullage to reduce or eliminate the ability of an ignition source to ignite the fuel vapor/air mixture. Prior work had established that—even with military threats such as high-explosive shells—reducing the oxygen content of the ullage to less than 10% would eliminate ignitions. The 1998 ARAC FTHWG proposed the concept of using GBI as a means of reducing tank flammability.

The FAA has conducted research on the quantity of nitrogen or NEA needed to inert a simple tank, the cost of providing NEA to the fleet, and—in cooperation with the industry—the use of GBI on a 737 airplane.

To support this research, the FAA has also developed an inerting computer program to assess the oxygen content in the fuel tank ullage over a complete flight. The model can add NEA to the tank ullage at any time and vary both the quantity and quality of the NEA. The model computes the amount of oxygen and nitrogen present in the tank—both in the ullage and dissolved in the fuel—and the fuel vapor in the ullage at 1-min time steps, from the time the airplane arrives at the gate to be fueled, through its fueling, dispatch, flight, landing, and taxi-in at the destination airport.

This model uses Coordinating Research Council (CRC) solubility coefficients (*CRC Aviation Handbook, Fuels and Fuel Systems*, no. Naval Air Systems Command no. 06-5-504, May 1, 1967) to compute the amount of oxygen and nitrogen dissolved in the fuel, and then uses an exponential decay process to transport the gas out of or back into the fuel, depending on the driving partial-pressure differential.

During climb, the exponential time constant is reduced considerably to allow for the more rapid gas evolution seen while climbing. The FAA used data from the 737 flight test to fine-tune the constants used in the model. The model computes ullage gases based on the change in tank pressure and the amount of NEA or air added in the 1-min increments. NEA and existing gases mix instantaneously, but the outflow of oxygen and nitrogen from the fuel needed to reach a pressure balance is assumed to lag the current oxygen content by 4 min, matching the FAA laboratory data.

The FTIHWG has used this model to assess the effectiveness of different inerting systems, including GBI and several forms of onboard NEA generation and delivery systems. The effectiveness of the inerting system can be used to assess tank fleet flammability exposure, as discussed in the following paragraphs.

4.2.2 Flammability Exposure Analysis

The 1998 ARAC FTHWG studies developed a Monte Carlo simulation technique to assess fleet fuel tank flammability exposure.

This method used the thermal characteristics of a fuel tank, the given distribution of missions the airplane would fly, and a model of the range of ambient temperatures experienced to compute the tank temperature for every minute of a large number of flights. Simultaneously, this method compared the fuel tank temperature to the lower and upper flammability limits (LFL and UFL) of the fuel presumed to be loaded for that flight. From this, it was possible to determine the fleet flammability exposure, which is the number of minutes the tank temperature is in the flammable range relative to the total operational time of the airplane. The 1998 ARAC FTHWG showed that CWTs exposed to nearby heating sources would have a flammability exposure of around 30% and unheated wing tanks would have a flammability exposure of around 5%.

The 1998 ARAC FTHWG used proprietary thermal models and Monte Carlo analysis programs developed by participating manufacturers. To conduct its own assessment of flammability exposure, the FAA developed its own Monte Carlo flammability analysis program. The 1998 ARAC FTHWG and FAA made their programs available to the ARAC FTIHWG for use and enhancement as needed to conduct the appropriate studies.

The program follows the original ARAC concept of computing flammability for any number of flights and obtaining a fleet-average exposure.

Because the 1998 ARAC FTHWG was studying a range of generic airplane types, it developed a set of generic tank thermal characteristics. The concept defined an exponential time constant for the tank temperature response to changes in ambient temperature and an equilibrium temperature difference (relative to ambient temperature) to represent the thermal effect of heat input to the tank. A tank will respond to a change in ambient temperature by following an exponential decay curve to the new equilibrium temperature, defined as the new ambient temperature plus the temperature difference from heating. The program used different values for ground and flight cases, and for full and nearly empty tanks. The need to switch from a full to a nearly empty tank is defined by airplane data and the tank in question. Manufacturers' proprietary data determined the specific values for the generic airplanes, which represent an average generic configuration. The constants used do not represent any actual airplane. Figure 4-1 shows these values.

Fuel tank thermal data	Ground-heated CWT			Flight-heated CWT		
	Equil. temp delta (°F)	Time constant		Equil. temp delta (°F)	Time constant	
Airplane type		Full (min)	Empty (min)		Full (min)	Empty (min)
Large transport	60	400	120	60	300	150
Medium transport	30	300	30	50	300	90
Small transport	37	300	25	50	300	90

Figure 4-1. Generic Tank Thermal Characteristics

A randomly selected ground temperature defines the atmospheric conditions for each flight by using a set of Gaussian distributions to define the range of temperatures and a randomly selected tropospheric temperature. The distribution of ground temperatures was based on 16 years of hourly temperature observations (7 a.m. to 11 p.m., local times) for 533 airports worldwide. The data was weighted based on the passenger volume for each specific airport. The climb period uses an interpolation scheme that computes the altitude of the tropopause and includes a temperature inversion on cold days.

A random value based on a distribution of flight lengths from fleet airline statistics determines the mission length for each flight, which is then scaled to match the maximum flight length of the generic airplanes.

Time on the ground is a random variable consisting of taxi-in time (set at 5 min), time before refueling (set at 5 min), refueling time (based on flight length and generic refueling rates), time at gate after refueling (based on a probability distribution from airline fleet statistics), and taxi-out time (set at 5 min). The approximate time on the ground for the generic large airplane is a minimum of 60 min, with 80% of the ground times shorter than 105 min and the maximum lasting 225 min. The approximate time on the ground for the small generic airplane is a minimum of 20 min (10% of flights), with 50% taking less than 50 min, 80% less than 75 min, and the longest taking 210 min.

Fuel flammability properties are defined by a randomly selected flash point for each flight and the effect of flammability temperature range computed as a function of altitude. The flash-point range is a normal Gaussian distribution, with a mean temperature of 120˚F, and a standard deviation of 8˚F. Generally, this results in a flash-point range of 100 to 140˚F.

The model can compute a single flight and present the flight profile and resulting flammability information as a plot, or compute the fleet flammability exposure for a given airplane type and tank for a Monte Carlo run of any number of flights. The ARAC analysis used computer runs of 5,000 flight cases.

Inerting systems such as GBI can be examined in the flammability model by creating a set of rules for the system using the inerting program discussed above. These rules compute when an increment of the flight is not flammable because the tank is inert, resulting in reduced fleet flammability exposure.

The team uses the results of the flammability exposure analyses for the generic airplane types and tanks to compute the effectiveness of candidate systems at preventing potential future accidents.

4.2.3 GBI Analysis

GBI was analyzed by adding a set of rules that inerted the center tanks with the volume of 95% NEA necessary to reach 8% with an empty tank. The inerting is a step function inserted at 50% of the time at gate after refueling. Had additional modeling time been available, the team would have evaluated actual inerting flow time and varied time at the gate, though this rule seemed likely to represent the average airline operations. Section 5, Ground-Based Inerting System, presents the results of the GBI analysis.

4.2.4 OBGI Analysis

OBGI was analyzed to ensure that the ullage contained 10% or less oxygen concentration. This concentration had to be achieved while the airplane was parked at the terminal gate. The NEA purity depended on the technology being analyzed. The size of the system was highly dependent on the time available at the gate to inert the fuel tanks. A flammability exposure analysis was then performed to compare the OBGI system to the other technologies.

Hybrid OBGI was analyzed in exactly the same way except that it was able to take advantage of an additional 5 min during taxi-in, after landing, to inert the fuel tanks. This slightly decreased the system size compared to OBGI, while maintaining the same flammability exposure.

4.2.5 OBIGGS Analysis

OBIGGS was analyzed to ensure that the ullage contained 10% oxygen or less during all phases of flight. The NEA purity depended on the technology being analyzed. Based on the 737 flight testing conducted by the FAA, where the tanks remained inert for several hours after receiving nitrogen, it was assumed that OBIGGS would not operate on the ground.

Hybrid OBIGGS was designed to provide the same flammability exposure as the GBI, OBGI, and hybrid OBGI systems. The focus was on ensuring that the flammability exposure during ground operations, taxi, takeoff, and climb were consistent with the other systems.

4.3 FUNCTIONAL HAZARD ANALYSIS

Because some of the inerting concepts involve technologies not currently fully mature or proven in a commercial airline environment, rigorous and detailed safety analyses could not be performed down to the component level with confidence. However, the team did perform a top-level FHA, which is included in appendix H, Safety Analysis Task Team Final Report.

4.4 PERSONNEL HAZARDS

4.4.1 General

Nitrogen and other inert gases are not normally dangerous, but when used in confined spaces they can create oxygen-deficient atmospheres that can be deadly. Nitrogen is especially hazardous, because it cannot be detected by human senses and can cause injury or death within minutes. In the United States, at least 21 people have died in 18 separate incidents involving the use of nitrogen in confined spaces between 1990—when more stringent requirements were adopted—and 1996. Every year in the United Kingdom, work in confined spaces kills an average of 15 people across a wide range of industries, from those involving complex plants to those using simple storage vessels. Fatalities include not only people working in confined spaces, but also those who try to rescue them without proper training or equipment. Still more people are seriously injured.

The health risk to ground and maintenance personnel servicing airplanes that use nitrogen inerting technology is present not only in the fuel tanks themselves, but also in the location of the nitrogen-generating equipment. Wherever possible, such equipment should be located outside the airplane pressure hull. However, this is not possible on all airplanes. Therefore, it will be necessary to ensure that safety systems and procedures are in place to protect the airplanes and personnel working in and around them.

The following sections highlight some of the hazards associated with operating fuel tank inerting systems on commercial transports and the risks they pose to the airplane, its occupants, and maintenance personnel.

4.4.2 Confined Spaces

The Occupational Safety and Health Administration (OSHA) defines a confined space as a space that by design

- Has limited openings for entry and exit.
- Has unfavorable natural ventilation.
- Is not intended for continuous employee occupancy.

OSHA further defines a permit-required confined space as a confined space with

- Hazardous atmosphere potential.
- Potential for engulfment.
- Inwardly converging walls.
- Any other recognized safety hazard.

By this definition, all airplane fuel tanks meet the OSHA definition of a permit-required confined space. If the tanks were to be inerted, the current requirement to ventilate fuel tanks before entering would be critical. In addition, other locations under consideration for housing nitrogen-generating equipment, such as cargo holds, wheelwells, wing-to-body fairings, and APU bays, may also be considered confined spaces. As such, appropriate entry procedures must be in place to minimize the risk to workers entering these spaces. These areas should be clearly marked and workers thoroughly educated regarding both the hazards of confined-space entry and the insidious nature of nitrogen asphyxiation and death.

The costs associated with implementing these additional confined-space entry procedures worldwide are estimated at $39.8 million for safety equipment and an additional $28.3 million per year in labor (see addendum F.E.1 in appendix F). Even with these procedures in place, accidents will continue to happen as a result of people bypassing or simply ignoring the procedures, as is proven annually by the current record of injuries and fatalities.

4.4.3 Gaseous Nitrogen

The most significant hazard associated with exposure to nitrogen is breathing the resulting oxygen-deficient atmosphere. Normal atmosphere is made up of approximately 21% oxygen, 78% nitrogen, and 1% argon, with smaller amounts of other gases. Nitrogen, which is colorless, odorless, and generally imperceptible to normal human senses, requires the use of oxygen-monitoring equipment to detect oxygen-deficient atmospheres. Despite its nontoxic profile, nitrogen can be quite deadly if not properly handled.

It is not necessary for nitrogen to displace all the 21% of oxygen normally found in air to become harmful to people. OSHA requires that oxygen levels be maintained at or above 19.5% to prevent injury to workers. Figure 4-2 summarizes the expected symptoms at various oxygen concentrations for people who are in good health.

Oxygen concentration, % volume	Symptoms	Maximum exposure
19.5	None	NA
14 to 19.5	Labored breathing, particularly at higher workloads	NA
12 to 14	Physical and intellectual performance impaired, increased heart rate	NA
10 to 12	Rapid breathing, dizziness, disorientation, nausea, blue lips	10 min
8 to 10	Loss of control, gasping, white face, vomiting, collapse	• 50% of people will not survive 6 min • 100% of people will not survive 8 min
4 to 8	• Coma • Death	• 40 sec • 2 min
<4	Death	Seconds

Figure 4-2. Personnel Hazards

The very nature of oxygen deficiency is that the victim becomes the poorest judge of when he or she is suffering from its effects. Victims may well not be aware of their condition and could fall unconscious without ever being aware of the danger.

4.4.4 Liquid Nitrogen

For OBIGGS, which uses cryocooling methods, liquid nitrogen presents its own specific hazards. Although relatively safe from the point of view of toxicity, liquid nitrogen—in common with all cryogens—presents the following hazards:

- Cold burns, frostbite, and hypothermia from the intense cold.
- Overpressurization from the large volume expansion.
- Fire from condensation of oxygen.
- Asphyxiation in oxygen-deficient atmospheres.

Skin contact with liquid nitrogen can cause tissue to freeze, resulting in severe burns, which are caused by the extremely low temperature of the cryogenic liquid, not by a chemical reaction. Liquid nitrogen contacting the airplane structure may cause degradation of materials, especially deterioration of composites and stress cracks in aluminum, and could result in structural failure.

The risk of oxygen-deficient atmospheres when using liquid nitrogen arises from the vast expansion of the substance as it boils or vaporizes. Just 1 L of liquid may produce around 700 L of gas at atmospheric pressure, displacing significant quantities of breathable air if the gas is released in a confined space such as an airplane fuel tank or pressure hull. The tendency of cool nitrogen to accumulate at low levels, where it is less easily dispersed than the ambient atmosphere, compounds this problem. Even an apparently small spill could lead to dangerously low oxygen levels, presenting a serious hazard to personnel and other occupants in the area.

Oxygen condensation from the atmosphere as a result of extreme cold is another potential hazard of using cryogens. Liquid oxygen can create highly flammable conditions, and may also create local oxygen-enriched atmospheres, presenting a greatly increased risk of fire or explosion should an ignition source be present.

4.4.5 Gaseous Oxygen

Gaseous oxygen, a byproduct of the nitrogen generation process, presents its own potential hazards. OBIGGS concepts are designed to vent oxygen overboard; however, some form of leak detection would need to be in place. Failure to provide such detection may result in an oxygen-rich atmosphere with associated risk of fire and explosion. Many materials that would normally only smolder in air, such as clothing, will burn vigorously in an oxygen-enriched atmosphere, making it essential that staff members are alerted to high oxygen concentrations so that the risk of fire can be minimized.

4.5 SAFETY BENEFIT ANALYSIS

The safety benefit forecast approach is based on the conclusions drawn from the service history review. Specifically, analysis showed that the tank explosion rate is not the same for all tank types. Further, there are similar types and numbers of potential ignition sources within all tanks, so one can expect the ignition event occurrence rate to be essentially the same for all tanks. It follows that different flammability exposures for the different tank types result in different explosion rates between wing tank and heated CWTs. Furthermore, there are differences in the exposure to potential ignition sources. On average, for example, potential ignition sources in wing tanks are submerged in fuel—and thus incapable of causing an event—more often than they are in CWTs, which are not filled if maximum airplane range is not needed.

The explosion rate for heated CWTs was calculated directly from the three events mentioned earlier. Explosion rates for each of the other tank types were determined based on their exposure to flammable vapors and the likelihood that the potential ignition source would not be submerged. Figure 4-3 shows the three events on which the analysis was based, along with the total worldwide fuel tank accident forecast.

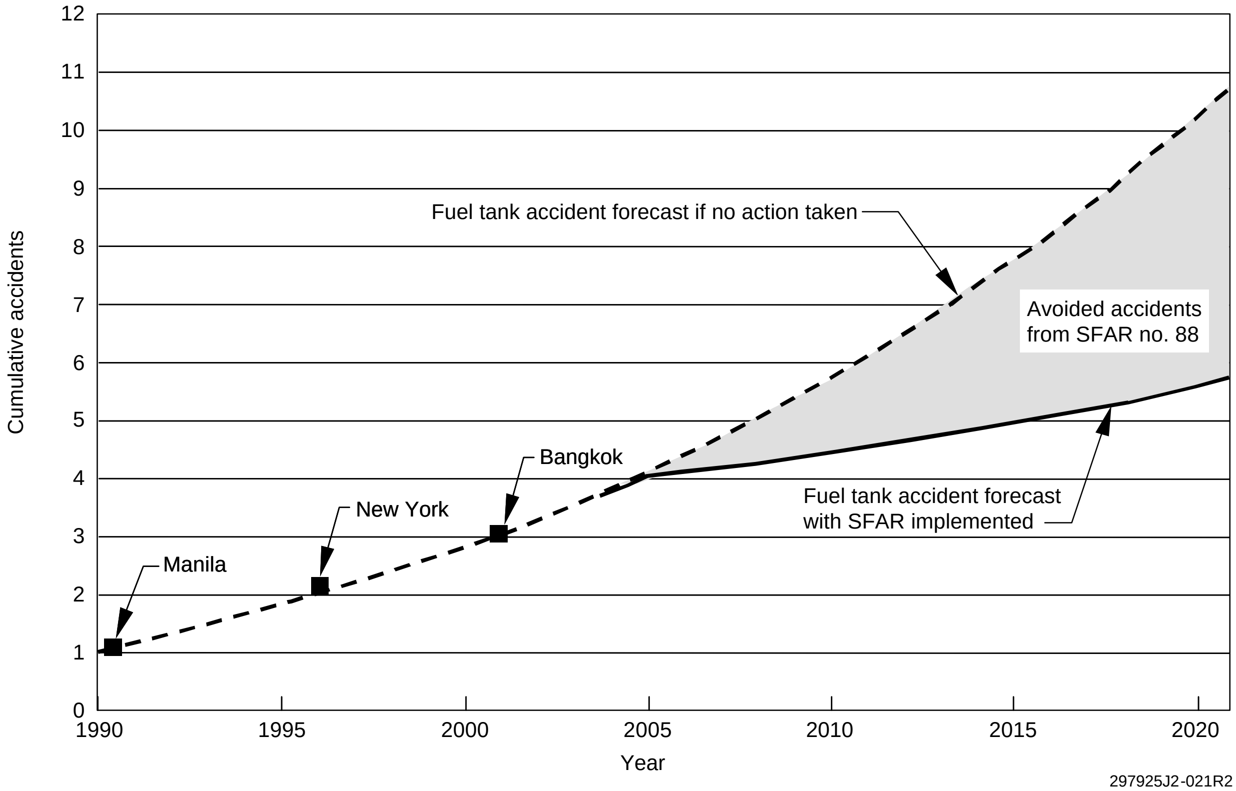

Figure 4-3. Worldwide Unexplained Fuel Tank Explosion Accident History and Forecast

This is the baseline accident forecast if no action is taken to preclude future events. Of the accidents forecast in figure 4-3, approximately 90% are predicted to involve heated CWTs.

In figure 4-3, the avoided accidents analysis takes into account predicted reductions in accident rate of 75% attributable to SFAR no. 88. The 75% reduction had been estimated by the 1998 ARAC FTHWG. In addition, the Safety Team had reviewed the 1998 report and fuel tank safety enhancements as a result of recent AD actions and other improvements. Although consensus was not reached by the FTIHWG, the majority of the HWG considered that using the 75% predicted reduction in fuel tank explosions was reasonable.

In addition, design, implementation, and forecast fleet growth all have a role in the number of forecast accidents that can be avoided. Appendix G, Estimating and Forecasting Task Team Final Report, documents these assumptions.

The number of prevented fatalities from a fuel tank explosion depends on the number of accidents avoided and the number of passengers on board. The number of passengers on board is a function of whether the explosion occurs in flight or on the ground. Based on the flammability exposure after inerting it was estimated that 15% of avoided accidents would have otherwise occurred on the ground, the other 85% in flight. It was also assumed that 10% of the people would die in a ground explosion, while an in-flight explosion would be a complete loss of everyone on board. These two assumptions were based on the historical accident record. The average number of passengers depends on the size of the airplane and the expected load factor.

Using the six generic airplane categories, the FTIHWG estimated that the average number of seats is 350 (plus 12 crew) for a large turbojet, 255 (plus 9 crew) for a medium turbojet, 154.5 (plus 7 crew) for a small turbojet, 65 (plus 5 crew) for a regional jet, 45 (plus 4 crew) for a turboprop, and 11 (plus 3 crew) for a business jet. Based on the FAA Aviation Forecasts Fiscal Years 2001–2012, the load factors are 75% for a large turbojet, 73% for a medium turbojet, 71% for a small turbojet, 60% for a regional jet and turboprop, and 40% for a business jet. Figure 4-4 summarizes the average number of people on board each of the generic airplanes based on these assumptions.

	Large transport	Medium transport	Small transport	Regional turbofan	Regional turboprop	Business jet
Passengers and crew onboard	275	195	117	44	31	7

Figure 4-4. Average Number of People on Board Each Generic Airplane

Figure 4-5 summarizes the number of forecast accidents avoided due to GBI (sec. 5.5), OBGI (sec. 7.6), and OBIGGS (secs. 8.6 and 9.6).

	Large transport	Medium transport	Small transport	Regional turbofan	Regional turboprop	Business jet
Worldwide accidents avoided by applying GBI to HCWT only	0.24	0.09	0.54	No HCWT	No HCWT	No HCWT
Worldwide accidents avoided by applying OBGI to HCWT only	0.20	0.09	0.47	No HCWT	No HCWT	No HCWT
Worldwide accidents avoided by applying OBIGGS to HCWT only	0.25	0.10	0.56	No HCWT	No HCWT	No HCWT
Worldwide accidents avoided by applying OBIGGS to all tanks	0.28	0.12	0.63	N/A	N/A	N/A

Figure 4-5. Worldwide Accidents Avoided by GBI and OBIGGS

In addition to preventing in-flight and ground fuel tank explosions, inerting also offers a benefit in enhancing occupant survival in accidents from other causes that result in a postcrash fuel tank fire or explosion. These benefits are discussed in section 3.2.2. It was found that GBI could save 5 lives worldwide over the study period, while OBIGGS could save 101 lives worldwide.

It must be observed that implementing fuel tank inerting on a global scale would introduce new hazards that previously did not exist in commercial aviation. Present wherever nitrogen is handled in the aviation infrastructure, these risks could be mitigated largely through stringent measures, but they could not be entirely eliminated.

Nitrogen is a colorless, odorless, nontoxic gas that is impossible to detect when excessive concentrations displace the oxygen normally present in the atmosphere. Depending on the level of oxygen depletion, the effects on people range from decreased ability to perform tasks to death through asphyxiation.

The adoption of inerting would introduce two types of hazards. The first would be the risk of confined-space asphyxiation from fuel tank entry for maintenance purposes. This risk is well understood and could be mitigated through training and procedures. A second and more insidious risk is the formation of localized oxygen-depleted zones as a result of undetected nitrogen leaks at airline and third-party maintenance facilities, on board airplanes, or—in the case of GBI—in airport ramp and terminal environments. Careful system design and rigorous procedures would be required to mitigate this latter risk scenario.

The FTIHWG lacked the time and expertise to assess these risks with confidence. However, the FTIHWG felt it was important to bound the risk. To do this, a simple extrapolation of available OSHA and National Institute of Occupational Safety and Health (NIOSH) data was used. According to 1980–1989 NIOSH data, the confined-space accident rate is between 0.20 (for the transportation industry) and 0.68 (for the oil and gas industries) per 100,000 employees. Of these, 43% were due to "Hazardous

Atmosphere - O2 deficiency." Assuming that these were all inert-gas related (e.g., argon, nitrogen, and carbon dioxide), this would result in a confined-space asphyxiation rate of 0.086 to 0.292 per 100,000 employees. According to OSHA, there were 1.2431 million U.S. airline employees in 1999. This would suggest the U.S. airline industry could expect 1.07 to 3.6 fatalities per year. In 1993, OSHA implemented more rigorous confined-space permit rules and estimated those rules would reduce fatalities by 85% in the United States. Assuming these rules are as effective as initially estimated, they could reduce U.S. airline industry fatalities to between 0.16 and 0.54 per year. The United States accounts for approximately 46% of worldwide airplane operations, and it was assumed that an OSHA-equivalent confined space regulation did not exist in the rest of the world. That results in a non-U.S. airline industry fatality rate of 1.26 to 4.23. The fatality rate from confined-space asphyxiation from nitrogen for the total worldwide airline industry is 1.42 to 4.77 per year. Based on assumed annual fleet growth rates and inerting system implementation assumptions, it is forecast that between 24 and 81 lives may be lost over the study period. Neither OSHA nor NIOSH participated in the FTIHWG. It is recommended that those agencies evaluate this risk based on current data before implementing inerting on a global scale.

Figure 4-6 summarizes the lives affected worldwide by inerting over the study period.

Lives affected over study period, 2005 through 2020	GBI, HCWT	OBGI, HCWT	OBIGGS, HCWT	OBIGGS, all tanks
Lives saved from fuel tank explosions in flight	125	112	132	149
Lives saved from fuel tank explosions on ground	2	2	2	3
Lives saved from post-crash fires	5	5	5	101
Lives lost due to asphyxiation	24 to 81	24 to 81	24 to 81	24 to 81

Figure 4-6. Summary of Lives Affected Worldwide by Inerting

Based on the last 10 years' accident records, there are approximately 650 fatalities per year worldwide resulting from airplane accidents. Assuming the worldwide accident rate remains constant and applying the unconstrained fleet growth assumption, over 15,000 fatalities could result from airplane accidents—from all causes—that could occur over the study period. The lives saved from inerting represent approximately 1% of that total.

4.6 SAFETY ASSESSMENT SUMMARY AND CONCLUSIONS

Over the past 12 years, the fuel tank explosion rate has remained essentially constant. Based on this observation and the forecast fleet growth, the occurrence of fuel tank explosions will be more frequent in the future. Ignition source reduction associated with SFAR no. 88 will provide a reduction in the fuel tank explosion rate.

Figure 4-7 shows the pre-SFAR no. 88 fuel tank explosion accident rate for each of the generic airplane families. Figure 4-8 shows how the accident rate is reduced by SFAR no. 88, GBI, and OBIGGS.

When evaluating the data in figure 4-7 and figure 4-8, it is important to understand that inerting systems offer little benefit to three of the six generic airplane families (regional turbofan, regional turboprop, and business jet) because none have heated CWTs and flammability of the wing tanks is already low. Furthermore, onboard systems were not found to be practical for these airplanes. One might expect the estimated time to the next accident for the OBIGGS scenario in figure 4-8, for example, to be longer. For airplanes equipped with OBIGGS (large, medium, and small transports) it is much longer still, on the order of 100 years. When forecasting so far into the future (and maintaining the unconstrained fleet growth assumption in att. B), the regional turbofan, regional turboprop, and business jet all contribute to the forecast. As a result, rather than the estimated time to the next accident being on the order of 100 years, it is forecast to be 51 years.

The flammability levels achieved by inerting systems can result in an improvement in the fuel tank explosion rate.

	Large transport	Medium transport	Small transport	Regional turbofan	Regional turboprop	Business jet	Total
Accident rate pre-SFAR no. 88	8×10^{-9}	8×10^{-9}	8×10^{-9}	6×10^{-10}	1×10^{-10}	4×10^{-10}	5×10^{-9} (weighted average)

Figure 4-7. Accident Forecast Summary Information

	Pre-SFAR no. 88	With SFAR no. 88 fully implemented	With SFAR and GBI of heated CWT fully implemented	With SFAR and OBIGGS of all tanks fully implemented
Estimated time to next accident in the United States after full implementation in year 2015	4	16	36	51
Explosion rate per operating hour for entire fleet (weighted average of all six generic airplane families)	5×10^{-9}	1.3×10^{-9}	3×10^{-10}	1.5×10^{-10}

Figure 4-8. Fuel Tank Explosion Accident Rate Comparison

5.0
Ground-Based Inerting